CAUSTIC EMBRITTLEMENT OF BOILER PLATE AND RIVET STEEL

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COMPREHENSIVE data exists on the present state of knowledge regarding caustic embrittlement of boiler plate steel. Extensive research work has been done on the subject in America. England and Germany. A review on the work done on the subject is given by Colebeck, Smith & Powell.[1] Parr and Straub[2] established the main features of this type of embrittlement from which later investigators took their clues. Co-related abstracts of Partridge and Schroeder[3] remain the standard of reference down to 1935. These researches have narrowed down the conclusions to two somewhat divergent schools of thought. Both views are, however, in agreement that the caustic embrittlement cracks differ widely from those ordinarily met with in common failures of metals such as fatigue or progressive cracks, fractures produced by direct tension and bending under dynamic and static stresses, etc. The latter cracks are usually transcrystalline, *i.e.*, the path of fracture runs across or through the crystals. Caustic embrittlement cracks in boiler steel are, however, typically intercrystalline following closely the grain boundaries.

The American and British researches have shown that the presence of alkali in the boiler-feed water and stress in the metal are essential for caustic embrittlement failures. Hydrogen absorption in the metal may also play an important part. Obviously no boiler-feed water can, in its normal state, contain enough alkali to cause cracking. The trouble, however, originates at leaky riveted seams and joints when alkaline feed water penetrates and fails to circulate freely thereby causing concentration of alkali due to evaporation of the water in the capillary spaces. As a result concentrated solution and even solid incrustations are formed in the capillaries of the respective joints and seams of boiler plates. A cracked boiler on dismantling reveals strongly alkaline whitish-brown incrustations at the joints between the plates and around the rivets. With the above condition another factor must also be present to cause cracking and that is high stress in the metal. Internal stress resulting from cold work through bad-riveting, excessive hammering bending for forming the drums, caulking, etc., is most important.

The stress must also exceed the yield point of the metal. Correcting by force, bad alignment of rivet holes, heavy caulking to ensure parallelism between the edges of the plates, excessive rivetting, pressure and use of improper snap-heads for riveting, etc., all contribute to introduce stress in the metal. Without, however, optimum chemical condition of water, the stress in the metal by itself is unlikely to contribute towards caustic embrittlement. Thus there should be first (1) Leakage in the joints that allows concentration in the capillaries of the boiler seams. (2) An embrittling boiler water and (3) High stress in the metal. Embrittling boiler feed water has been found to contain high alkalinity with low sulphate contents. Boiler Code Committee of A.S.M.E. have recommended ratios of sulphate to alkalinity as a precautionary measure against embrittlement as follows :—

Boiler pressure lbs. per sq. inch	0–150	150–250	over 250
Ratio of sulphate and alkalinity	1	2	3

However, cases of intercrystalline cracking have been recorded in boilers where the above ratios were consistently maintained. Straub and Bradbury[4] have recommended a sodium sulphate/total alkalinity ratio greater than 1·0 together with sodium chloride/total alkalinity ratio above 0·6 for steam pressure upto 250 lbs. per sq. inch.

The addition of phosphate to the water has not been reported to be effective where the chloride/alkalinity ratio fell below 0·2. Alumina additions have been reported to prevent embrittlement at higher boiler pressures above 500 lbs. per sq. inch. For intermediate boiler pressures of 350 lbs. per sq. inch both the chloride/alkalinity and sulphate/alkalinity ratio and also the ratios expressed by R_2O_3/SiO_2 appear to play an important part in controlling embrittlement.

The second school of thought sponsored by German workers in the field tends to hold the steel responsible for boiler plate failures and claims that to be satisfactory, the steel must be specially resistant to corrosion attack under extreme conditions of temperature and pressure. The paper by Athavale[5] represents the German Data on the subject claiming that alkali is not the chief cause of the embrittlement but rather the type and quality of steel and the local stresses that are present in the boiler; that caustic embrittlement depends upon hydrogen absorption; and upon precipitation hardening phenomena due to the presence of nitrogen in steel. Germans have recommended the use of Izett non-ageing aluminium steels to prevent cracking.

The above claims have not been substantiated by Americans and British researches. Original Germans work which was undertaken following a disastrous boilers explosion in 1920, formed the Vereinigung der Grosskesselbesitzer. Their work ignored Parr and Straub's well-established features but emphasized the process of ageing in steel at boilers operating temperatures. Germans Izett non-ageing steel was expected to possess immunity to caustic embrittlement but it was later shown to fail in much the same way as boiler mild steel. Later German results have fallen in line with the results of others.

The term caustic embrittlement is a misnomer just as fatigue cracking is. As pointed out by Desch[6] the steel between the cracks does not become "brittle" but is merely fissured along the grain boundaries through external influences.

Caustic embrittlement has not been reported from welded or seamless drum boilers owing to complete absence of leaky rivetted joints providing narrow capillary spaces for concentration of alkalies, etc., unless at joints or fittings.

The author has examined a number of cases of caustic embrittlement failures of boiler plates and rivets. The results of some of the typical investigations are discussed below:—

In one case cracks were observed to have started from the rivet hole, extending into the interior of the plate as shown in Fig. 1. Fig. 2 shows the crack starting from the edges of a rivet hole at the joint between the boiler plates. Evidence of excessive rivetting pressure was left on the boiler plate in the form of deep circular indentations around the rivet holes made by the snap during rivetting as shown in Fig. 2. Deposits of reddish brown scale consisting of magnetic oxide of iron were observed in the crevices and at the contact surfaces of the lap joints from where pittings and several incipient cracks were observed to radiate. The reaction that takes place at the joints is:—$3Fe + NaOH + 4H_2O \rightarrow Fe_3O_4 + NaOH + 4H_2$.

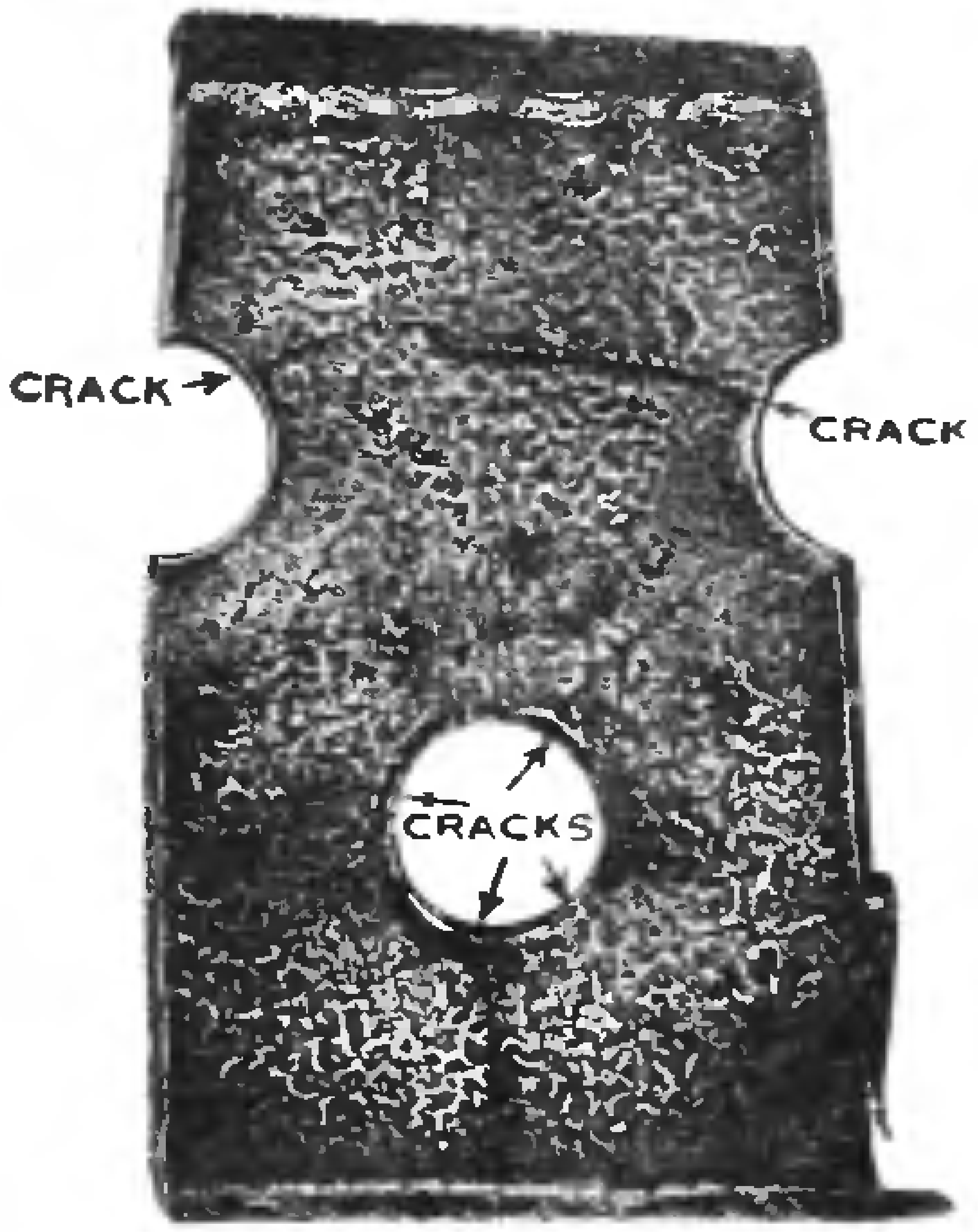


FIG. 1

Cracked Boiler Plate showing caustic-embrittlement cracks starting from rivet-hole edge

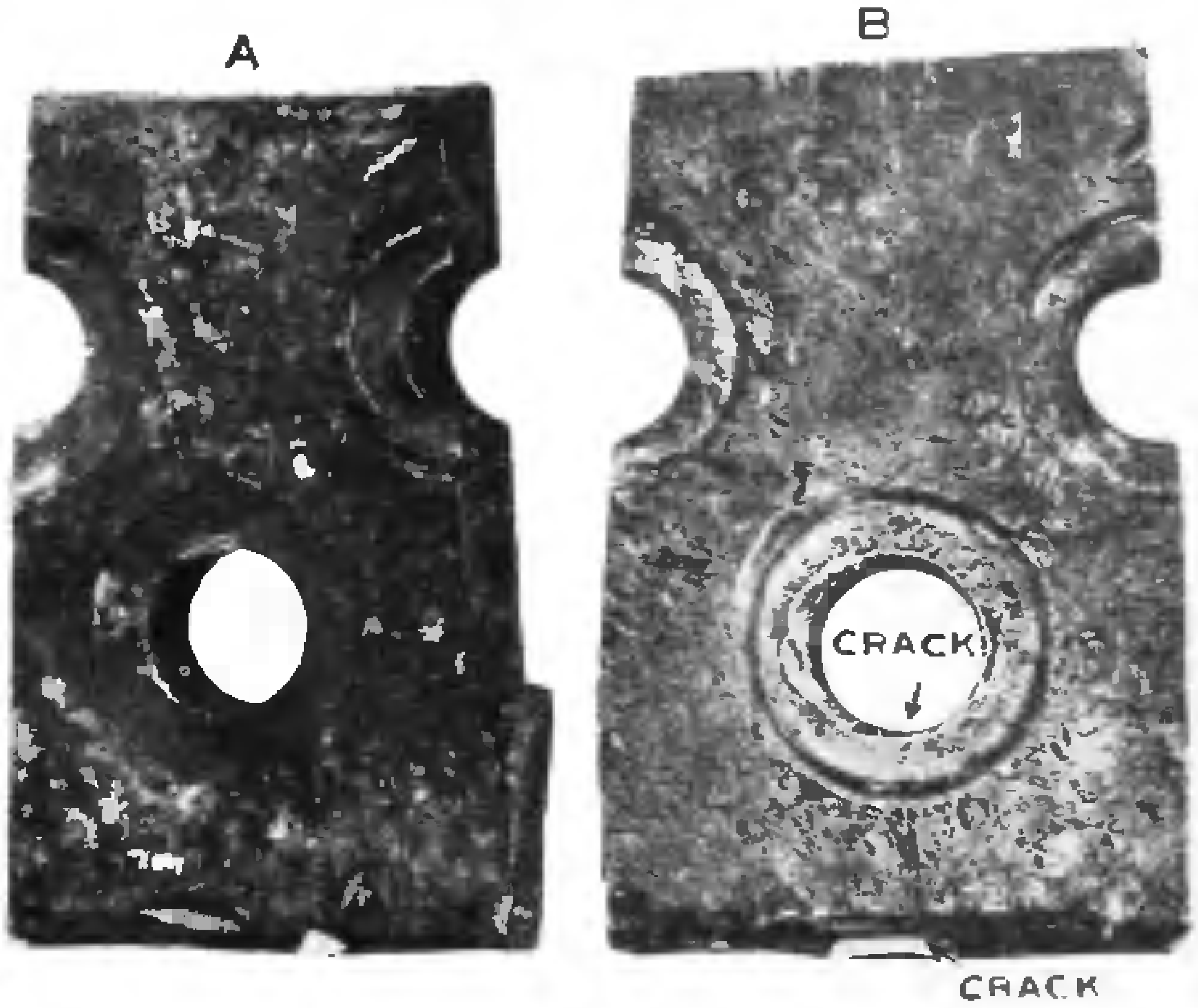


FIG. 2

Cracked Boiler Plate showing fine cracks and deep circular indentations around rivet holes

Samples of boiler feed water gave the following results on chemical analysis :—

		$\frac{Na_2CO_3}{NaOH}$ ratio	$\frac{Na_2SO_4}{NaOH}$ ratio	$\frac{Na_2SO_4}{\text{Total alkalinity expressed as } Na_2CO_3}$
1	Boiler parts taken through glass gauge cock	2·19	0·15	0·78
2	„ „ „	1·26	1·89	0·28
3	Boiler blow down	0·72	0·61	0·22

Analyses of boiler steel gave the following results :—

Carbon	..	0·18%
Manganese	..	0·56%
Silicon	..	0·105%
Sulphur	..	0·027%
Phosphorus	..	0·035%

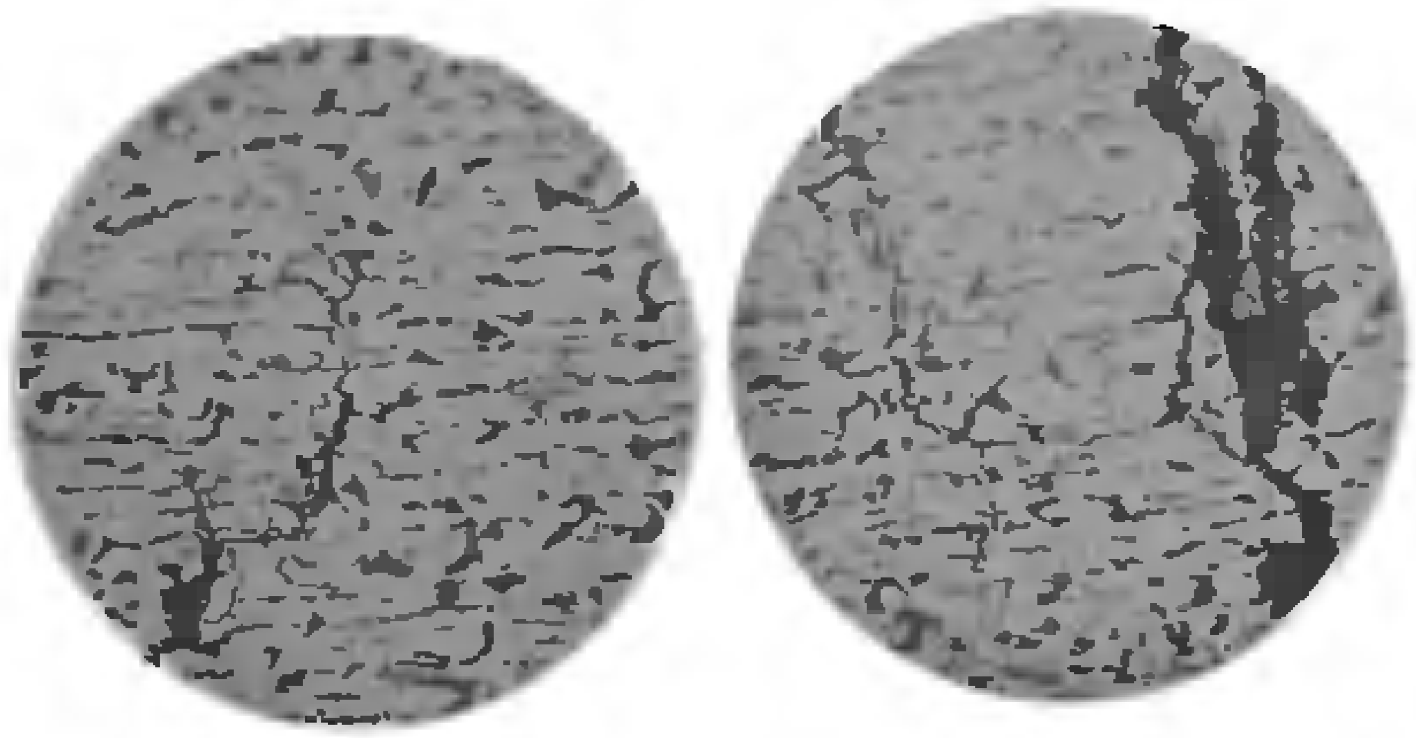
Hardness Test.—Hardness values were determined by means of the Vickers pyramid hardness testing machine using 30 kg. load on the surface of the cracked plate starting from the rivet hole edge, at intervals of 1/16" apart, with the following results : 138, 136, 135, 139 V.P.H. Nos.

Brinell Hardness test with 3000 kg. load on the surface of the plate ¾" away from the rivet hole gave a value of 137 B.H.N. The approximate tensile strength of the boiler shell plate calculated from the hardness value was about 30 tons per sq. inch.

Bend Test.—Test piece taken from the defective plates away from the cracked area, could be successfully bent through 180° without showing any signs of cracking at the outer surface of the bend.

Macro Examination. — Sulphur Print taken on a longitudinal section of the plates failed to reveal any abnormality. Macro-etching of the same sample showed satisfactory structure. Sulphur Print taken on the longitudinal section of one of the rivets showed freedom from sulphur segregation. On macro-etching some of the rivets, fine circumferential cracks were revealed on the undersurface of the rivet heads near the junction of the shank and head as shown in Fig. 5. Macro-structure of the rivets appeared to be satisfactory.

Microscopic Examination.— Section taken from near the cracked areas of the plate showed the normal fine-grained Sorbo-Pearlite and ferrite structures. Radial cracks starting from the edges of the rivet holes were observed. The main cracks had considerably opened out through corrosion. Several branching cracks were also observed. The branching cracks were observed in every case to be inter-crystalline as depicted in photo-micrographs Nos. 3 and 4. The main cracks had in most cases extended out to either side of the plate.



3 50 4 50

FIGS. 3 & 4

Showing micro-structure of the Boiler Plate and inter-crystalline caustic embrittlement cracks

FIG. 5

Circumferential cracks in the boiler rivet at the junction of the shank head—considerably opened out through corrosion

Conclusions.—The results of chemical analysis and physical tests showed that the material of the boiler plate was of satisfactory quality. Macroscopic and micro-examination showed that the material was normal for Boiler quality plates and was free from abnormalities.

The inter-crystalline nature of the cracks starting from the edges of the rivet holes was definitely established by microscopic examination — a phenomenon associated with caustic embrittlement of boiler plates. That there was apparently leakage of water contents of the water in the capillaries of the imperfect and leaky rivet joints where the boiler feed water could not circulate freely, was evident from the deposition of solids at the plate joints and in the crevices. The boiler plate around the rivet-holes had been damaged through bad riveting as depicted in Fig. 2 showing deep circular indentations around the rivet holes made by the snap during riveting. This had not only damaged the boiler plate, distorted the rivets and the rivet-holes, thereby causing an imperfect and leaky joint to develop but also had left the joints and seams in a state of severe stress—one of the essential causes of caustic embrittlement and cracking of boiler plates at the rivet joints. Such cracking of the boiler plates has always been known to be inter-crystalline in nature and micro-examination of the cracked regions of the boiler plate in the present case corroborated the inter-crystalline failure of the metal. The boiler water, judged from its chemical analysis, was probably not of an embrittling character although the controversy around the chemical analysis of embrittling and non-embrittling types of boiler waters, is still far from séttled in the technical literature.

In the present case the caustic embrittlement of the boiler plate appeared probably, to be due to the rivet joints and seams having been in a state of stress by riveting which through damaging the plate, distorting the rivets and rivet-holes, had formed a leaky and imperfect joint. This caused leakage of water and consequent concentration and deposition of the mineral contents of the water and oxides of iron therein at normal boiler temperatures. Due to the same causes, the rivets had also developed cracking as shown in Fig. 5.

Another case of caustic embrittlement of the boiler rivets showed whitish-brown alkaline deposits at the area of contact between the rivet head and the boiler plate as shown in Fig. 6. In this case the rivet-heads were severed off from the shank through caustic embrittlement of the rivets. The chemical composition as well as the quality of the steel of the rivet was quite normal.

FIG. 6

Whitish-brown alkaline deposits at the underside of the rivet heads

Another case of caustic embrittlement cracking of the boiler plate showed the formation of cracks from rivet-holes and whitish incrustation on the plate as depicted in Fig. 7. The cracks on microscopic examination showed their inter-crystalline nature as shown in Micro-photograph 8. The boiler-plate steel was of sound

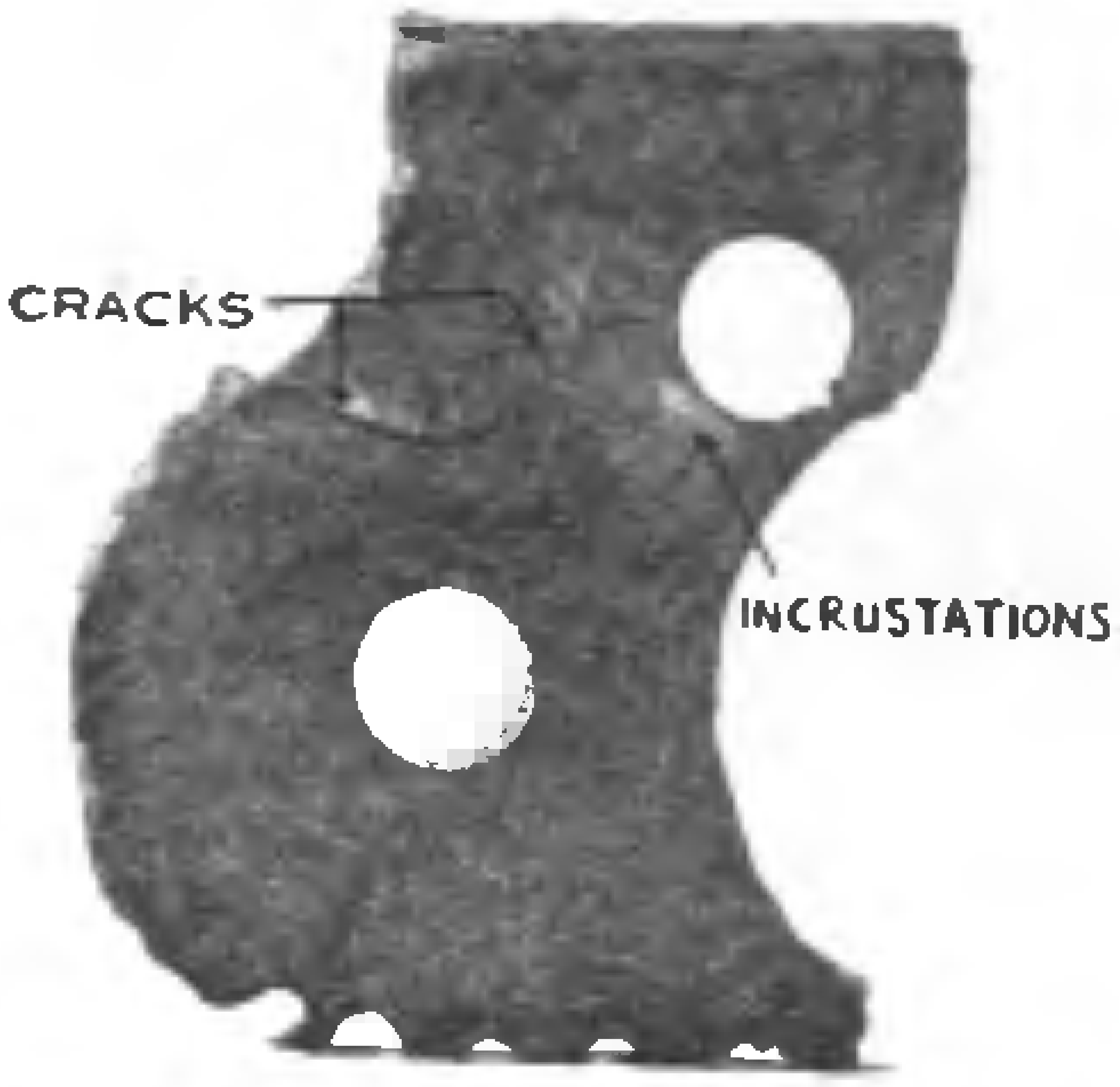


FIG. 7

Showing caustic embrittlement cracks at the rivet holes and whitish incrustations on the plate's surface

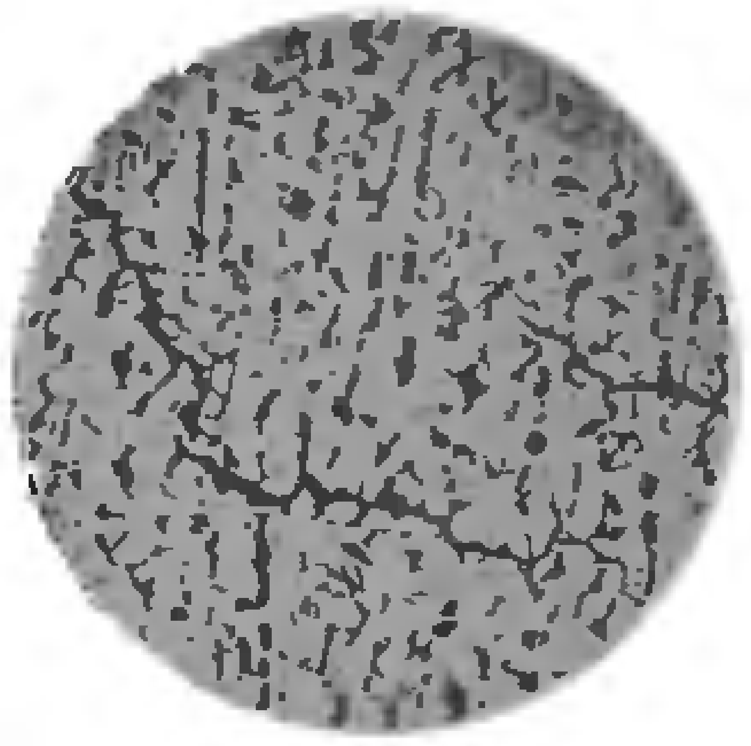


FIG. 8

Showing intercrystalline cracking in Boiler Plate owing to caustic embrittlement

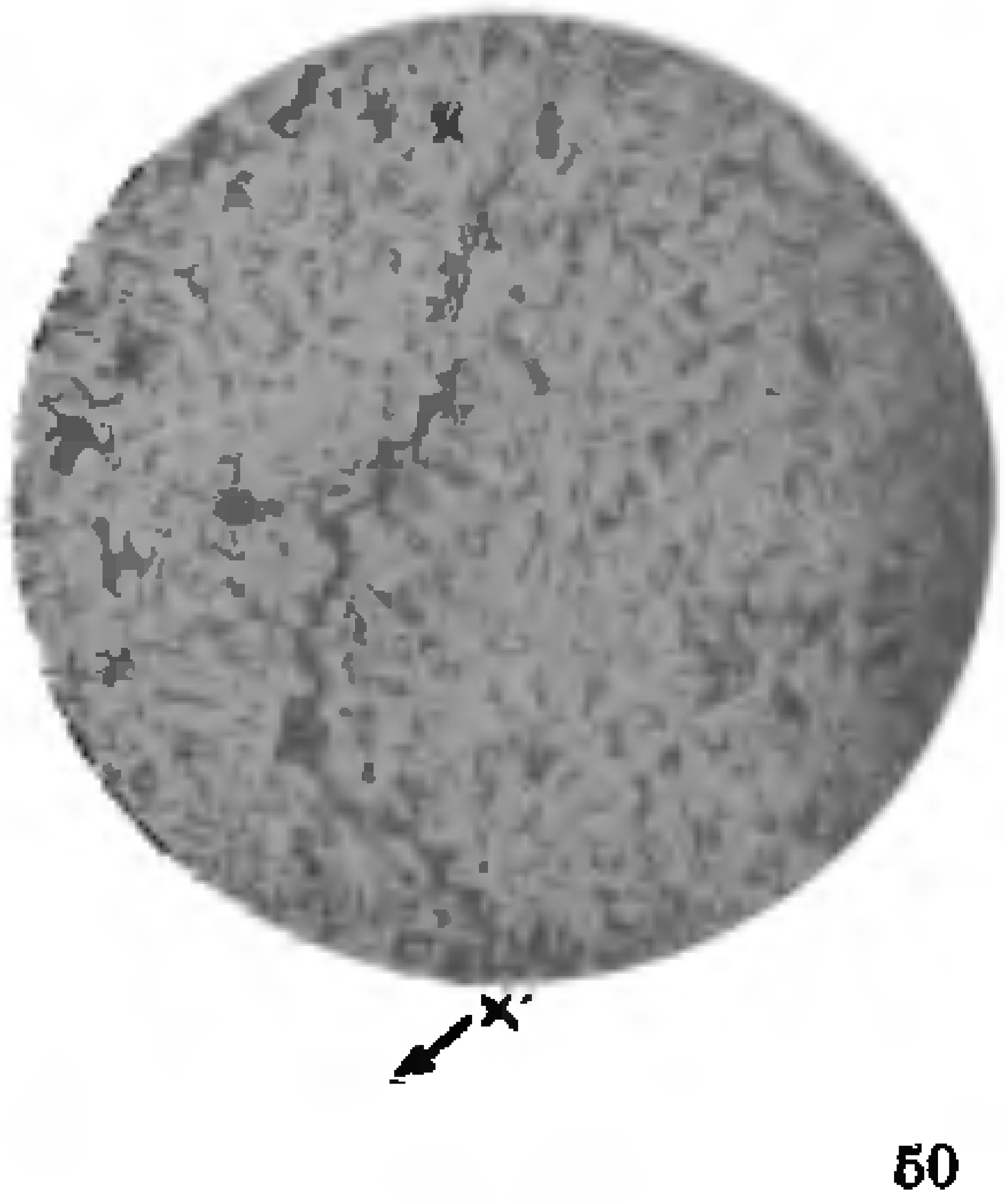


FIG. 9

Inter-crystalline cracking in boiler rivets due to caustic embrittlement

XX' shows the path of the crack.

quality and composition, showed freedom from abnormalities on micro and macroscopic examinations and gave very satisfactory physical properties on testing.

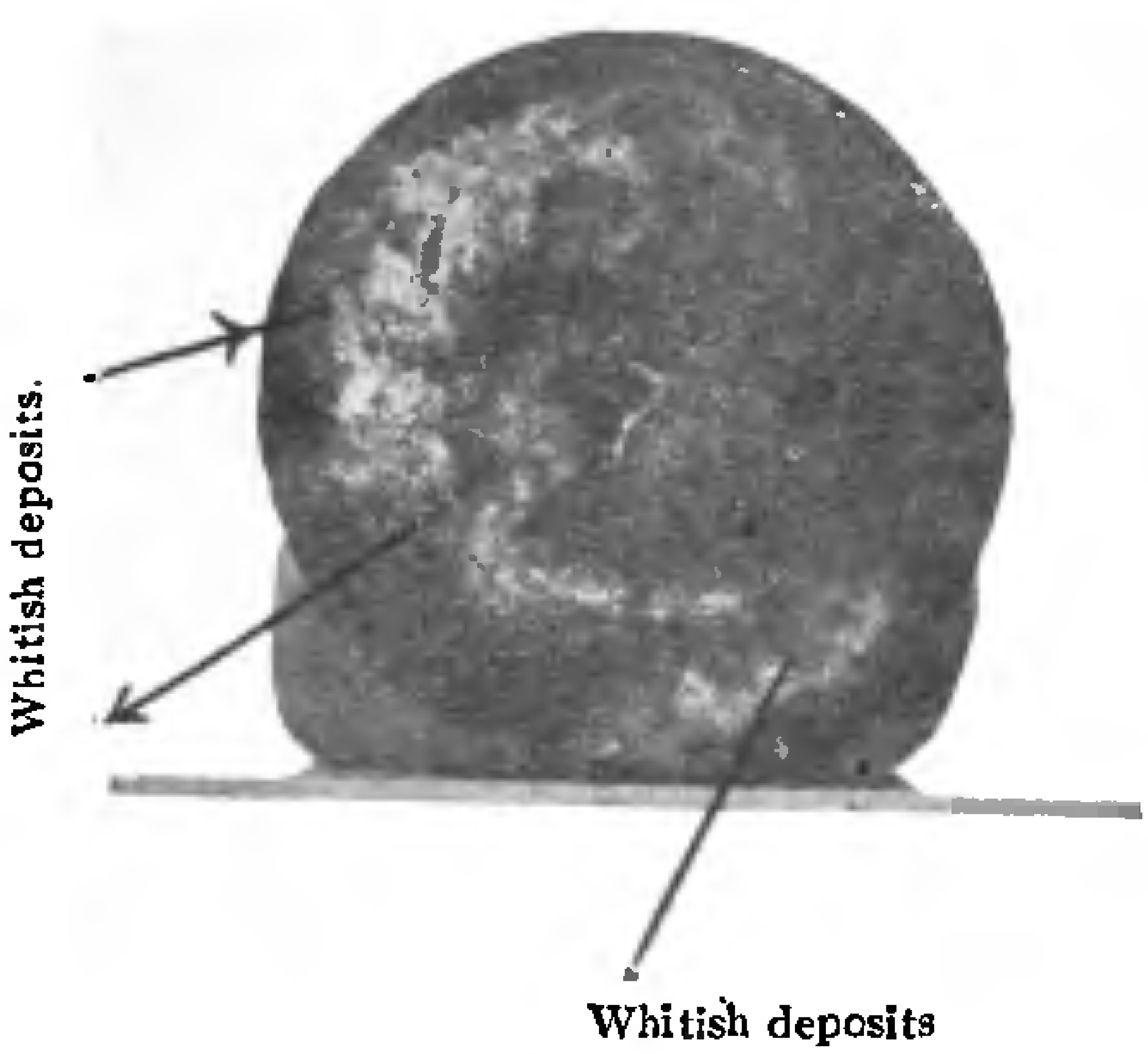


FIG 10

Whitish alkaline deposits at the rivet head

In another similar case of boiler-rivet failure inter-crystalline cracking and whitish alkaline deposits at the rivet heads are depicted in Figs 9 and 10. The rivet steel itself gave excellent properties on physical and metallurgical tests. Its chemical composition conformed to I.R.S. specification No. M7-39 for boiler quality rivets.

1. Colbeck, Smith and Powell, "Metal Treatment, Winter, 1942-43," **9**, (32), 171. 2. Parr and Straub, *Proc. Amer. Soc. Test. Mat*, 1926, (26), 52. 3. Partridge and Schroeder, *Metals and Alloys*, 1935, **6**, 145; *Ibid.*, 1935, **6**, 355; *Trans. Amer. Soc. Mech. Engrs.*, 1936 **58**, 223. 4. Straub and Bradbury, *Mech. Eng.*, 1938, **60**, 371. 5. Athavale, *Korrosion and Metallschutz*, 1939, **15**, 73. 6. Desch. J., *Iron and Steel Inst.*, 1941, **143**, 94

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NATURE CONSERVATION AND NATIONAL PARKS

THE concept of nature conservation embraces several distinct purposes such as conservation of plant and animal life, the scientific aspect which includes biological research; field research and experiment; the amenity aspect which deals with æsthetic and recreational side and the educational aspect. The æsthetic and recreational approach placed the main emphasis upon preserving the characteristic beauty of the landscape and upon providing ample access and facilities for open-air recreation and for the enjoyment of beauty in those areas. The major features of the Park are made easily accessible by providing roads, trails and bridges, and living accommodation in the form of hostels, etc. The scientific approach which in no way underestimates the æsthetic values, was primarily directed to the advancement of knowledge and its application to human welfare. "The educational aspect" as the Special Committee on Wild Life Conservation observes "is in many ways complementary to each and all of the others. True appreciation of scenery rests in part upon, and is certainly enhanced by, some understanding of the rocks and the variety of landscape which these induce, the shapes of the rocks and the variety of landscape which these include, the shapes of the valleys and summits, the flow of the streams, the cliffs and dunes and flats of the coast, and all the rich verdure with which they are clothed, are things which can invigorate and refresh the mind and upon which a deep culture can be based. The more widely this appreciation can be diffused, the sounder will be the mental and physical health of the nation."

The type of areas which are in need of conservation can be classified under the following categories:—

I.—*National Parks and Nature Reserves*: National Parks may be defined as extensive areas of beautiful and relatively wild country with characteristic landscape beauty which are also wild life sanctuaries for the preservation of big game, or other mammals and birds, in which access and facilities for public open air enjoyment are also provided, so that the people may be able to observe wild life of all kinds in its natural surroundings at close quarters. There is also need of nature reserves in the national parks, which act as breeding reservoirs for shy animals, which it is desired to encourage and which are not accessible to visitors.

II.—*Geological Monuments and other areas of outstanding value*: These include rocks, exposures or sections which because of their great geological interest should be preserved as Geological Monuments, and which

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